USGS
science for a changing world

NORTH DAKOTA
STATE WATER COMMISSION

Lake Levels, Streamflow, and Surface-Water Quality in the Devils Lake Area, North Dakota, Through 1997

Introduction

The Devils Lake Basin is a 3,810-square-mile (mi^2) closed basin (fig. 1) in the Red River of the North Basin. The basin is contributing only when the level of Devils Lake is greater than 1,459 feet (ft) above sea level (asl). About 3,320 mi^2 of the total 3,810 mi^2 is tributary to Devils Lake; the remainder is tributary to Stump Lake.

Since glaciation, the lake level of Devils Lake has fluctuated from about 1,459 ft asl, the natural spill elevation of the lake to the Sheyenne River (Bruce Engelhardt, North Dakota State Water Commission, oral commun., 1998), to 1,400 ft asl. Although no documented records of lake levels are available before 1867, Upham (1895, p. 595), on the basis of tree-ring chronology, indicated that the lake level was 1,441 ft asl in 1830. Lake levels were recorded sporadically from 1867 to 1901 when the U.S. Geological Survey established a gaging station on Devils Lake. From 1867 to the present (1998), the lake level has fluctuated between a maximum of 1,443.0 ft asl in 1997 and a minimum of 1,400.9 ft asl in 1940 (fig. 2). On January 31, 1998, the lake level was 1,442.7 ft asl, about 20.1 ft higher than the level recorded in February 1993.

Since 1993, the lake level of Devils Lake (fig. 2) has risen rapidly in response to above-normal precipitation from the summer of 1993 to the present, and 50,000 acres of land around the lake have been flooded. The above-normal precipitation also has caused flooding elsewhere in the Devils Lake Basin. State highways near Devils Lake are being raised, and some roads have been closed because of flooding.

In response to the flooding, the Devils Lake Basin Interagency Task Force, comprised of many State and Federal agencies, was formed in 1995 to find and propose intermediate (5 years or less) solutions to reduce the effects of high lake levels. In addition to various planning studies being conducted by Federal agencies, the North Dakota State Water Commission has implemented a project to store water on small tracts of land and in the chain of lakes (Sweetwater Lake, Morrison Lake, Dry Lake, Mikes Lake, Chain Lake, Lake Alice, and Lake Irvine). North Dakota's flood solutions include options to manage and store water in the Devils Lake Basin, to continue infrastructure protection, and to provide an outlet to the Sheyenne River via West Bay Devils Lake. Outlet construction requires consideration of water-quantity and -quality issues in designing the operating plan. Therefore, current and accurate hydrologic information is needed to assess the viability of the various options to reduce flood damages at Devils Lake.

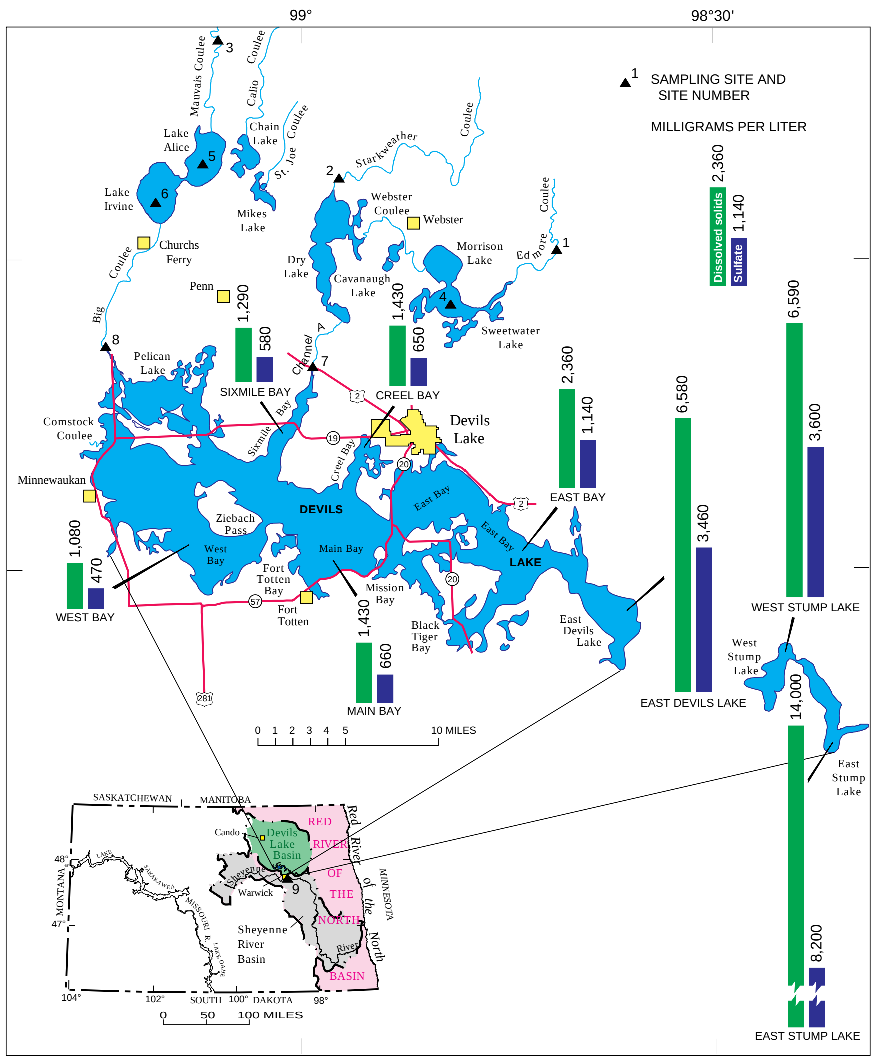

Figure 1. Location of the Devils Lake Basin and dissolved-solids and sulfate concentrations in Devils Lake and West and East Stump Lakes, 1997.

Lake Levels and Streamflow

Because of a large snowmelt runoff during the spring of 1987, the lake level of Devils Lake reached 1,428.8 ft asl (the highest level since the 1870s) in August 1987. A severe drought

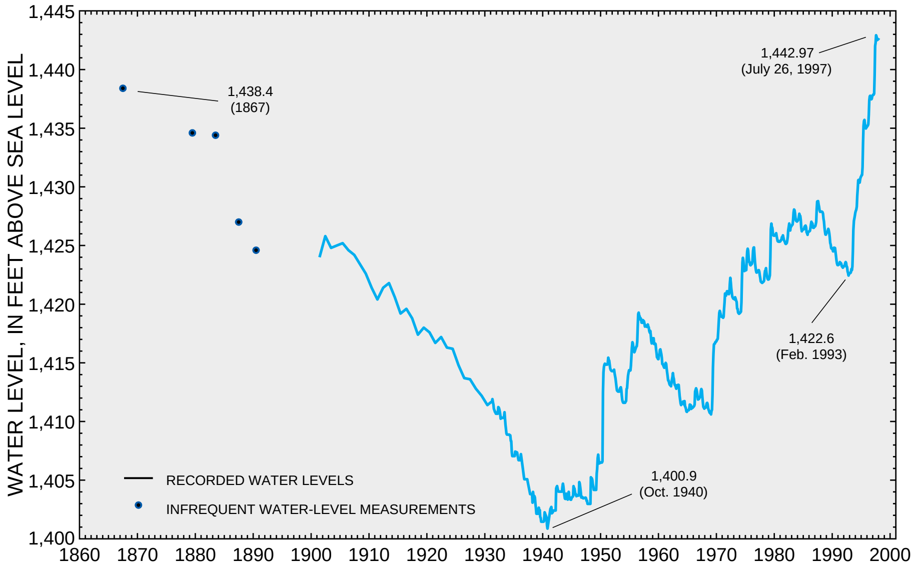

Figure 2. Historic water level for Devils Lake, 1867-1997.

began late in the summer of 1987, and the level declined to 1,422.6 ft asl by February 1993 (fig. 2). During the drought, the volume of water in storage decreased about 37 percent, from 884,000 acre-feet (acre-ft) in August 1987 to 558,400 acre-ft in February 1993.

The drought also caused lake-level declines on all lakes in the Devils Lake Basin, including the chain of lakes. For example, the level of Dry Lake was below the outlet elevation (1,445.0 ft asl) to Channel A from June 15, 1988, through April 22, 1989, and from June 4, 1989, through about February 28, 1992. Crops were planted in the lakebed of Lake Irvine during part of the drought. For 1988-91, streamflow in tributaries to the chain of lakes ranged from only 3 percent of the long-term average at Mauvais Coulee near Cando to 21 percent of the long-term average at Starkweather Coulee near Webster. Much-below-average streamflow into the chain of lakes and above-average evaporation from the lake surfaces during most of the drought produced little flow out of the chain of lakes into Devils Lake. Combined streamflow of Channel A and Big Coulee for 1988-92 (the period of rapid lake-level decrease) was only 26,000 acre-ft. Inflow from Channel A into Devils Lake from June 1988 through February 1992 was only 271 of the 26,000 acre-ft.

The 20.1-ft lake-level rise since February 1993 corresponds to a 1,604,000-acre-ft increase in storage in Devils Lake. The estimated average annual inflow to Devils Lake for 1950-97 is 86,030 acre-ft. Estimated annual inflow is 265,500 acre-ft for 1993; 205,600 acre-ft for 1994; 402,000 acre-ft for 1995; 279,600 acre-ft for 1996; and 521,900 acre-ft for 1997. Total inflow to Devils Lake for 1993-97 accounts for 41 percent of all inflow to Devils Lake for 1950-97.

Unusually high lake levels have been recorded on the chain of lakes at times since February 1993. Near-record maximum lake levels occurred late in the summer of 1993 and in the spring of 1995 on Sweetwater, Morrison, and Dry Lakes and on Lakes Alice and Irvine. Record maximum lake levels occurred on all lakes in the chain of lakes in April or early May 1997. For example, the maximum lake level (1,452.02 ft asl) for 1983-97 for Dry Lake occurred on May 2, 1997, when water from the lake spilled over the shoreline in the northwest part of the lake. Water that spilled out of the lake entered the old drainage system and reached Devils Lake via Mikes Lake, Chain Lake, Lake Alice, Lake Irvine, and Big Coulee.

Sporadic lake-level measurements were made on the Stump Lakes from 1949 through 1979 and from 1993 through 1997. Before 1995, the lake level of West Stump Lake ranged from about 1,394.0 ft asl in the dry years to about 1,400.0 ft asl in the wet years, and the lake level of East Stump Lake ranged from about 1,382.0 ft asl in the dry years to about 1,385.0 ft asl in the wet years. The lake-level variability of the Stump Lakes (3 to 6 ft) is less than the variability of Devils Lake (38 ft). Based on lake-level measurements through 1997, no sustained, major lake-level changes occurred on the Stump Lakes from 1949 until 1993.

Although no streamflow gages exist in the Stump Lakes drainage basin, quarterly lake-level measurements since 1993 and observations of local landowners and North Dakota State Water Commission and U.S. Fish and Wildlife Service personnel indicate that a relatively large amount of tributary runoff into West Stump Lake occurred late in the summer of 1993 and, by February 1994, the level of West Stump Lake was 1,395.8 ft asl. Runoff into West Stump Lake filled that lake and flowed into East Stump Lake during late 1993 and throughout 1994. By January 1995, West and East Stump Lakes were joined and the lake level was 1,398.0 ft asl. On July 28, 1997, the lake level of Stump Lake was 1,406.7 ft asl, the highest level in about 75 years.

The natural outlet for Devils Lake and the Stump Lakes is to the Sheyenne River. All of the options for a Devils Lake outlet would discharge water to the Sheyenne River upstream of Warwick. The drainage area of the Sheyenne River Basin, excluding the Devils Lake Basin, is 6,910 mi^2. Lake Ashtabula (normal full-pool capacity, 70,200 acre-ft), formed by Baldhill Dam, is the only major impoundment in the basin. The dam is operated to provide flood control, municipal water supplies, stream-pollution abatement, and recreation. The Devils Lake outlet will be designed for a maximum discharge to the Sheyenne River of 300 cubic feet per second (ft^3/s), and the operating plan will be designed to minimize downstream flood risks.

The long-term average annual streamflow of the Sheyenne River near Warwick is 62.4 ft^3/s. Daily average streamflows for 1990 and 1997 (fig. 3) indicate the large variability between a dry year (1990) and a wet year (1997). During 1990, streamflow was less than 50 ft^3/s almost the entire year; however, in 1997, streamflow was greater than 500 ft^3/s from April 1 through May 9 (39 days) and greater than 200 ft^3/s for 57 days.

Surface-Water Quality

The quality of surface waters, especially dissolved-solids concentrations, in the Devils Lake area is affected by many factors, such as climate, topography, and geology. Climate affects surface-water quality through variations in temperature and precipitation. For example, warm, dry periods increase lake evaporation and, thus, generally concentrate dissolved solids. Wet periods generally increase streamflow and lake levels and, thus, dilute dissolved solids. Topography and drainage affect surface-water quality by influencing the amount and rate of runoff. Dissolved-solids concentrations in streamflow generally are greater during low flow than during high flow because rapid runoff over frozen soil during the snowmelt period limits soil-water interaction (Lent and Zainhofsky, 1995).

Tributaries Upstream of the Chain of Lakes

In tributaries upstream of the chain of lakes, average dissolved-solids concentrations ranged from 365 milligrams per liter (mg/L) for Starkweather Coulee (site 2; fig. 4) to 605 mg/L for Mauvais Coulee (site 3; fig. 4). The

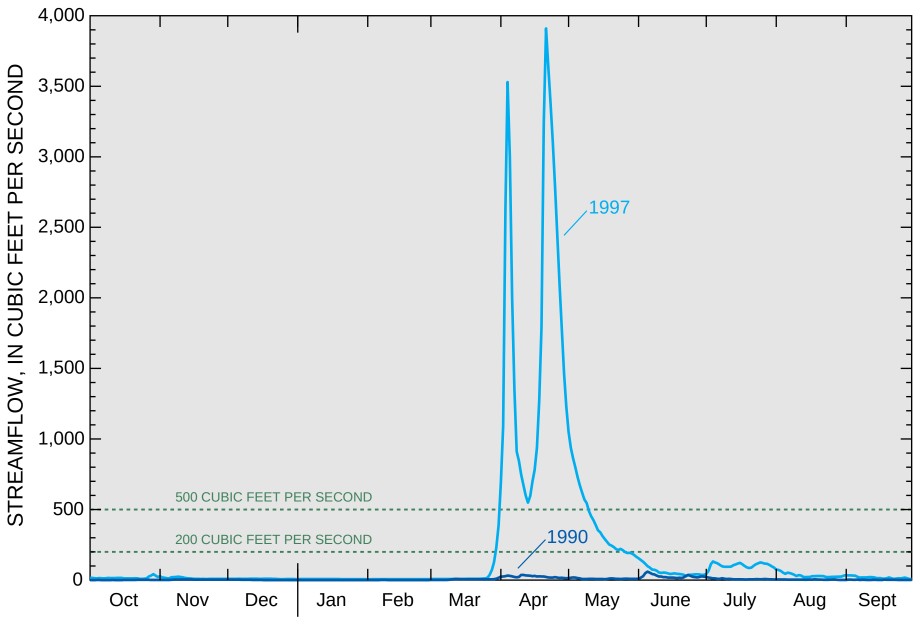

Figure 3. Streamflow for the Sheyenne River near Warwick for water years 1990 and 1997.

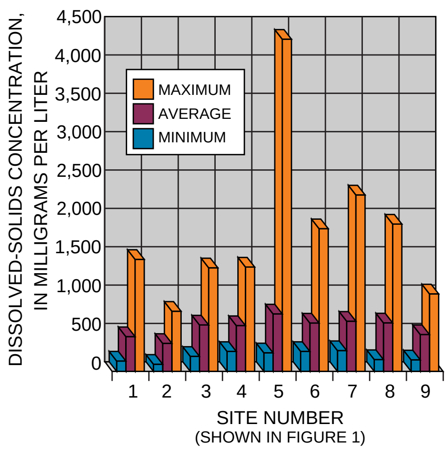

Figure 4. Dissolved-solids concentrations for streams and lakes in the Devils Lake area. [Period of record varies for each site and ranges from 1951 through 1997 for the Sheyenne River near Warwick (526 samples) to 1984 through 1997 for Channel A near Penn (67 samples).]

concentrations for water samples collected during 1993-97 generally ranged from 200 to 450 mg/L during high flow and from 450 to 1,000 mg/L during low flow.

Chain of Lakes and Downstream Tributaries

Dissolved-solids concentrations in Morrison Lake, Sweetwater Lake, Dry Lake, Lake Alice, and Lake Irvine are similar. Average dissolved-solids concentrations ranged from 597 mg/L for Sweetwater Lake (site 4; fig. 4) to 749 mg/L for Lake Alice (site 5; fig. 4). The period of record for dissolved-solids data is much shorter for Morrison and Dry Lakes than for the other lakes in the chain; thus, they are not included in figure 4. Dissolved-solids concentrations in Sweetwater Lake do not vary seasonally, but those in Lakes Alice and Irvine do vary seasonally. In Lakes Alice and Irvine, concentrations in the spring routinely were less than those during the remainder of the year. Seasonal variations indicate that the dissolved-solids concentrations of Lakes Alice and Irvine may be influenced by the seasonal variability of tributary inflows and by the concentrating effect of evaporation during the summer (Lent and Zainhofsky, 1995). Maximum concentrations (fig. 4) in the chain of lakes usually occur in the winter because the lake levels are at or near annual minimums at the time of freezeup, and ice formation increases the concentration of dissolved solids in the underlying water. Generally, average dissolved-solids concentrations (fig. 4) for the chain of lakes are higher than those for the tributaries to the lakes, and the variability of average dissolved solids in the chain of lakes is less than in the tributaries.

During 1984-92 (the years of corresponding record for Big Coulee and Channel A), too few samples were collected to compute water-quality statistics. However, dissolved-solids concentrations in Channel A (site 7; fig. 1) during 1993-97 ranged from 270 to 1,340 mg/L and averaged 483 mg/L. Concentrations in Big Coulee (site 8; fig. 1) averaged 455 mg/L but were less variable than those in Channel A. The concentrations ranged from 290 to 640 mg/L, except during low flow in January 1994 (720 mg/L).

Devils Lake

Devils Lake, which consists of several bays that are, to some extent, isolated from each other, is characterized by large fluctuations in lake level and in concentrations of dissolved solids. Dissolved-solids concentrations vary both spatially and temporally. Dissolved-solids concentrations generally increase from west to east in Devils Lake and East Devils Lake (fig. 5) as less-concentrated water enters the western part of the lake and becomes progressively more concentrated by evaporation as it moves eastward. Average concentrations during 1988-90 ranged from about 3,400 mg/L at four sites west of Highway 57 (fig. 1) to about 10,000 mg/L in East Devils Lake. By the fall of 1995, dissolved-solids concentrations in Devils Lake had decreased dramatically, and concentrations in the western part of the lake ranged from about 1,280 mg/L in West Bay to about 1,880 mg/L in Main Bay. Much-above-normal runoff into Devils Lake during 1996-97 caused a continued decrease in dissolved-solids concentrations, and concentrations in the western part of the lake ranged

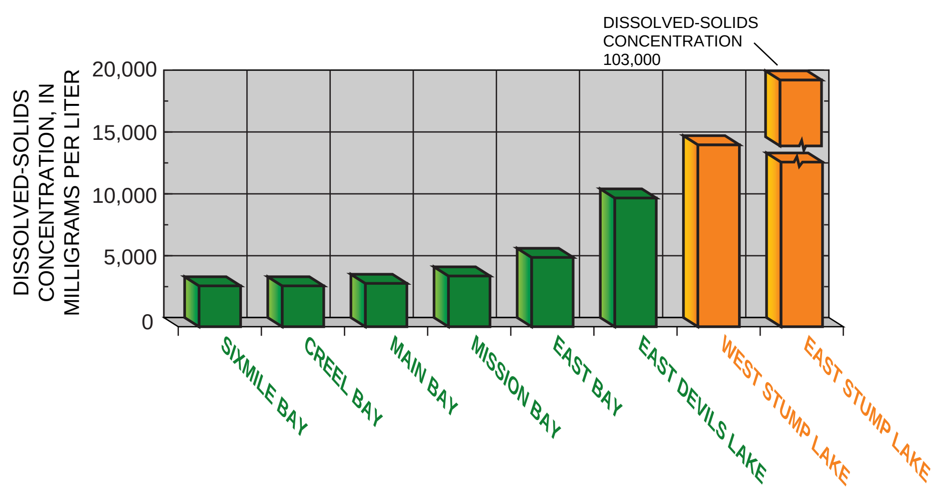

Figure 5. Average dissolved-solids concentration for selected locations in Devils Lake and West and East Stump Lakes. [Period of record varies for each site and ranges from 1949 through 1979 and from 1993 through 1995 for East Stump Lake (82 samples) to 1988 through 1990 for Mission Bay (11 samples).]

from 1,080 mg/L in West Bay to 1,430 mg/L in Main Bay and Creel Bay (fig. 1; North Dakota Department of Health, written commun., 1997).

Dissolved-solids concentrations generally are largest in winter when ions are concentrated because of ice formation and smallest in spring when water is diluted because of ice-melt, surface-water inflow, and precipitation. The concentrations generally increase in summer and fall when evaporation exceeds surface-water inflow and precipitation. Dissolved-solids concentrations of Devils Lake generally fluctuate inversely with lake level.

West and East Stump Lakes

The U.S. Geological Survey sampled West and East Stump Lakes sporadically from 1949 through 1979 and from 1993 through 1997. In June 1949, a detailed study of West Stump Lake determined that the lake was uniform in quality; dissolved-solids concentrations ranged from 5,950 to 6,090 mg/L. Since 1949, concentrations have ranged from 2,430 mg/L in May 1995 to 108,000 mg/L in September 1963 during a drought. In comparison, the dissolved solids in seawater is about 35,000 mg/L. On October 6, 1997, the concentration in West Stump Lake was 6,590 mg/L (fig. 1).

Dissolved-solids concentrations in East Stump Lake have ranged from 12,200 mg/L in May 1997 to 241,000 mg/L in July 1961. On October 6, 1997, the concentration in East Stump Lake was 14,000 mg/L (fig. 1). During 1993-94, the dissolved-solids concentrations in West and East Stump Lakes decreased dramatically because of dilution from the large amount of relatively fresh surface-water runoff. From 1995 through 1997, the dissolved-solids concentrations in East Stump Lake generally continued to decrease, but the concentrations in West Stump Lake began to increase. The increase started when the two lakes reached the same water level and the more-concentrated water from East Devils Lake started to mix with the less-concentrated water in West Stump Lake.

Sheyenne River

Average dissolved-solids concentrations for water samples collected from the Sheyenne River near Warwick (site 9; fig. 4) are about the same as those for Big Coulee (site 8; fig. 4) and Channel A (site 7; fig. 4), but the variability is less in the Sheyenne River. Concentrations for 526 samples collected from 1951 through 1997 from the Sheyenne River near Warwick ranged from 150 to 1,010 mg/L and averaged 480 mg/L.

Spatial variability of dissolved solids in Devils Lake and the Stump Lakes is an important factor in determining the pumping-plant size and outlet location to the Sheyenne River. For example, if 200 ft^3/s of water from West Bay Devils Lake is added to 200 ft^3/s of water in the Sheyenne River near Warwick, the dissolved-solids concentration in the river increases from 480 to 780 mg/L and the sulfate concentration increases from 96 to 280 mg/L (fig. 6). However, if the same amount of water is pumped from East Stump Lake, the dissolved-solids concentration in the river increases from 480 to 7,200 mg/L and the sulfate concentration increases from 96 to 4,100 mg/L.

References

Lent, R.M., and Zainhofsky, S.D., 1995, Variations in surface-water quality in the chain of lakes and its tributaries, Devils Lake Basin, North Dakota, 1957-92: U.S. Geological Survey Water-Resources Investigations Report 95-4102, 87 p.

Upham, Warren, 1895, The glacial Lake Agassiz: U.S. Geological Survey Monograph No. 25, 658 p.

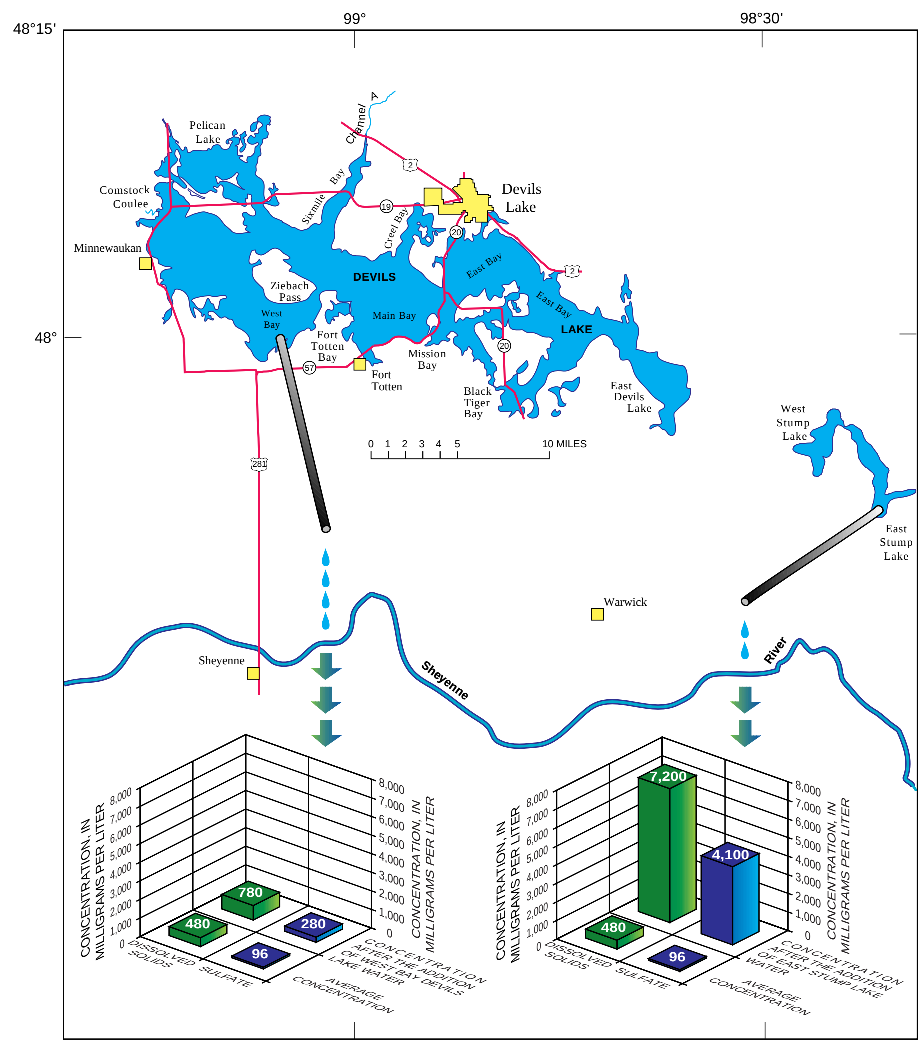

Figure 6. Average dissolved-solids and sulfate concentrations in the Sheyenne River near Warwick with and without the addition of water from Devils Lake.

For more information contact any of the following:

For water information:
District Chief
821 East Interstate Avenue
Bismarck, ND 58501
(701) 250-7400

For more information on all USGS reports and products (including maps, images, and computerized data), call 1-800-USA-MAPS.

Additional earth science information can be found by accessing the USGS "Home Page" on the World Wide Web at "http://www.usgs.gov".

Gregg J. Wiche, 1998